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FINAL REPORT

CONCEPTUAL DESIGN OF RESERVOIR DATA BASE: REVIEW OF USES AND SELECTED DESIGN ISSUES

by

James F. Pautz, Raymond J. Heemstra, and Carolyn A. Sellers

Work Performed for

U.S. Department of Energy

Under Cooperative Agreement DE-FC-22-83FE60149

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Project SGP28, Milestone 2, FY91

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CONCEPTUAL DESIGN OF RESERVOIR DATA BASE: REVIEW OF USES AND SELECTED DESIGN ISSUES

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ABSTRACT

This is the final report for phase 1 of the design of a reservoir data base for the Department of Energy (DOE) reservoir data archived at the Bartlesville Project Office (BPO). This phase consisted of an information requirements study and a review of the major conceptual issues for a reservoir data base. The conclusion of the information requirements study was that there are two major classes of users. The most important user in the past has been the DOE/BPO for model studies to determine the potential for enhanced oil recovery (EOR) and advanced oil recovery technologies under existing and proposed policy conditions. This use has been important in prioritizing the DOE oil research program and has assisted in the development of a new oil research program that has established a second major use – detailed reservoir analysis. These two dissimilar uses have similar data requirements. In a few situations, these uses are in conflict and will require a special method for managing this conflict. One example of conflict for the data base is dealing with the security of the data. Some of the DOE reservoir data were obtained from proprietary or commercial sources and require special safeguards to maintain the proprietary nature of the data.

The results of the new DOE oil research program, as well as expanding the need for the reservoir data, will expand the type of data included in the data base. The final design must account for easy expansion to include data from DOE demonstration projects. The RELIANCE data management system available on the BPO computer has features that can accommodate the needs of the data base. Because this is a relational system, many of the design parameters and issues will be transferable to other relational DBMS programs.

INTRODUCTION

The purpose of this study is to review the potential applications of a reservoir data base and design a system that will optimize the storage and retrieval of data for the major users and uses of the data. The purpose of this phase of the study was to complete an information requirements study and prepare a conceptual design.

Publicly available reservoir data will be useful to many people and can be used in many different ways. The data can be used by industry, academia, and government in studies of potential for techniques and products for advancing oil production as well as targeting areas for application. The current Department of Energy (DOE) reservoir data have been used by relatively few organizations because only limited sections of the data are available to the public. Although significant government funds have been spent to acquire data, the data management has been relegated to flat data files with limited data search and retrieval capabilities.

The primary use of the DOE reservoir data has been in computer model studies for determining the potential of enhanced oil recovery (EOR) under various conditions. Studies have successfully considered oil price variations, advances in technology, tax alternatives, impact of environmental regulations, and other factors to assist in the development of policies and programs at the state and federal level. The data collection emphasis was on data for the largest reservoirs and to assure that the data would give reasonable results when used with the DOE EOR predictive models. The first study resulted from a cooperative effort by oil companies and the federal government through the National Petroleum Council.[1] Some of the reservoir data were donated by oil companies for the reservoir data on the condition that the data be kept confidential. Data have been extracted from commercial data bases under the assumption that the data are for internal use of the government. Some petroleum information services have allowed unrestricted use of their data with the understanding that the data are not for public dissemination. Since previous study results were the results of computer modeling, data confidentiality could be maintained without affecting the quality of the study or the reporting of results.

Recently, an additional requirement has been to look at specific reservoirs and detailed geological characteristics of reservoirs. An area of special interest in the DOE oil research program[2] will be targeting specific classes of reservoirs and conducting demonstration projects. Additional geological data are being collected as well as engineering data on reservoirs to meet the new demands of this program direction. Specific reservoir data will be used to evaluate trade-offs between competing technologies and processes for application to geologically classified reservoirs. This additional requirement adds new criteria for data and expands the potential users of this data. Although the two use similar data, the differences present special data management problems and trade-offs that a formal data management system can optimize. The issue of maintaining data confidentiality while reporting results of a study of the data is more difficult with this second requirement. Because the second requirement deals with specific reservoirs, key conclusions about the selection of a particular reservoir for additional study and funding may be based on a mix of public domain data as well as proprietary or confidential data. Maintaining the confidentiality of data is more difficult while publicly justifying the research or project decisions. An issue exists when mixing data compiled for a group of reservoirs that produces reasonable results from computer models with data that have been reported in the literature but have inconsistencies with other data or insufficient data for operation of the computer models.

Data Sources

TORIS Reservoir Data

The DOE reservoir data base has evolved from numerous special studies of EOR potential. Each study has had specific objectives, and the reservoir data collection has addressed those objectives without using a commercial data management system. The data continue to be expanded both in quantity, complexity, and uses. This expansion suggests that data management is necessary to safeguard both the data and the users.

The DOE reservoir data is part of the Tertiary Oil Recovery Information System (TORIS), which had its beginnings in 1974. Figure 1 summarizes the major studies that have been conducted using TORIS.[3] During the first National Petroleum Council's study of EOR potential in 1976, it was determined that more complete information on United States reservoirs and the petroleum resource was needed to assess the potential for enhanced or tertiary recovery. This data base now resides at an EIA computer in Washington, D.C., in a System 2000 data base management system (S2K).

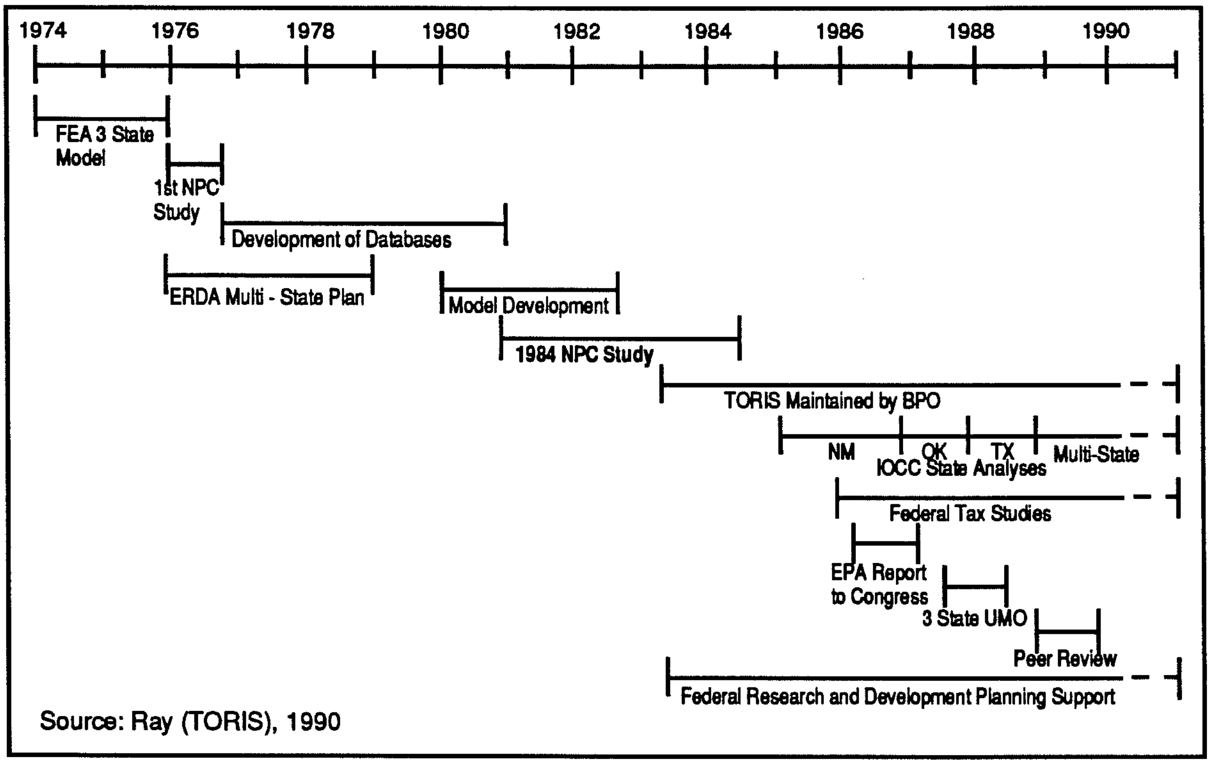

FIGURE 1. - History of the development of the TORIS data and analysis techniques.

The S2K reservoir data base was used as one main source of data for the 1984 EOR NPC study.[1] In addition, the participants of the NPC study submitted information about fields and reservoirs that they owned and/or operated. Often the data were given with the understanding that the information would remain confidential, and the companies were given assurances that the data would be kept confidential. In some cases, the information had incomplete identification that did not allow it to be incorporated in the data used for this NPC study and were available from public sources. The reservoir data for the 1984 NPC study was put into a flat file that consisted of five 250 byte records. The first four records were information about reservoirs appropriate for all EOR processes. The non-proprietary data in these four records are called the NPC public data base and have been available on request. The fifth record is used for selected EOR process that required special information. A specific fifth record was developed for steam, in situ combustion, and miscible gas candidate reservoirs. This basic structure continues to be used with some modifications for the current TORIS studies.

After the 1984 NPC study, data for EOR predictive model studies from various states have been targeted for review and improvement. NIPER analyzed and updated data for Louisiana, New Mexico, and Oklahoma as part of DOE/NIPER projects BE2 and OE1 from 1984 to 1986. Since 1986, ICF/Lewin has updated the flat file reservoir data with information collected as part of the IOCC State Analyses. An additional fifth record for geology has been added and is being populated with the results of a state-by-state study of reservoir geology.[4]

TORIS Flat File Reservoir Data

Extensive reservoir data have been developed for TORIS model studies and will be the basis of the new data base. This data file resides at BPO so it will be called either the flat file or the BPO data. It consists of roughly 4,100 reservoirs which represent over 70% of the original-oil-in-place that has been discovered in the United States. It has been cross-referenced to oil production in commercial data bases during various studies.

The meaning of reservoir has different connotations for different users. For the EOR predictive modeling use, this term meant oil pool that may or may not be contiguous throughout a field. This is similar to all the producing formations or a geological play within a particular field. For example, all the Bartlesville sands within a field or trend would be called the Bartlesville reservoir even if the formation were faulted into a number of different structural reservoirs. When oil production has been commingled from producing formations that are of similar geology and depth, development of statistics for a model-sensitive reservoir to represent a group of producing formations may be the best alternative. The data in the file (see table 1) consist of locator and identifiers as well as the data required to run the predictive models stored in four 250 byte records.

The TORIS modeling system has a default program that reads the four records and generates input files for the predictive models that include any missing data. As long as the reservoir data file has eight key data elements and the data are internally consistent, the default program will generate sufficient data for the predictive models. In addition to the base data, process specific data are required and are stored in a fifth record. The effect of geology on the applicability of advance recovery processes had been added by using the fifth record for geological information. Table 2 shows the information on three fifth records. A key portion of the geological information is a classification system that is driving the new Federal Implementation Plan.[2] Geological classification data have been compiled on roughly 2,200 reservoirs.

TABLE 1. - Data dictionary for the base file of the BPO reservoir data

DARY NO.	ACRONYM	DESCRIPTION	DARY NO.	ACRONYM	DESCRIPTION
1	FLDAC	FIELD ACRES OF RESERVOIR	2	PROVAC	PROVEN ACRES FOR RESERVOIR
3	WELSPAC	WELL SPACING (2 * FIELD ACRES / TOTAL WELLS)	4	TOTWEL	TOTAL WELLS (INJECTION + PRODUCING WELLS)
5	THICK	NET PAY OR THICKNESS OF PRODUCING FORMATION, FT	6	GROSS	GROSS PAY, FT
7	POROS	POROSITY, PERCENT	8	SOI	INITIAL OIL SATURATION, PERCENT
9	SO	CURRENT OIL SATURATION, PERCENT	10	SWI	INITIAL CONNATE WATER SATURATION, PERCENT
11	SW	CURRENT WATER SATURATION, PERCENT	12	SGI	INITIAL GAS SATURATION, PERCENT
13	SG	CURRENT GAS SATURATION, PERCENT	14	IFVF OR BOI	INITIAL FORMATION VOLUME FACTOR
15	CFVF OR BO	CURRENT FORMATION VOLUME FACTOR	16	DEPTH	DEPTH TO TOP OF PRODUCING FORMATION, FT
17	TRES	TEMPERATURE AT BOTTOM OF HOLE, DEG F	18	PRES	CURRENT FORMATION PRESSURE, PSI
19	PERM	AVERAGE PERMEABILITY, MD	20	GEOAGE	GEOAGE CODE (OR BASIN CODE)
21	API	API OIL GRAVITY, DEG. API	22	VOIL	OIL VISCOSITY, CENTIPOISES (CP)
23	SALN	RESERVOIR SALINITY, PPM	24	OOIP	ORIGINAL OIL-IN-PLACE, STB
25	PRIFAC	PRIMARY RECOVERY FACTOR, FRACTION OOIP	26	SECFAC	SECONDARY RECOVERY FACTOR, FRACTION OOIP
27	CUMREC	CUMULATIVE OIL PRODUCTION, STB	28	YCUMREC	YEAR FOR CUMULATIVE OIL PRODUCTION
29	PRIRBAC	PRIMARY RECOVERY, BBL/ACRE	30	PRIRBAFT	PRIMARY RECOVERY, BBL/ACRE-FT
31	PRIRBBL	PRIMARY RECOVERY, BBL	32	YPRIPROD	YEAR FOR PRIMARY RECOVERY
33	RS	CURRENT PRODUCING GAS/OIL RATIO (RS), SCF/BBL	34	SGOR	INITIAL GAS/OIL RATIO (SGOR), SCF/BBL
35	RESAC	RESERVOIR ACREAGE (RESAC), ACRES	36	IPRESS	INITIAL FORMATION PRESSURE, PSI
37	DIP	RESERVOIR DIP, DEGREES	38	PRODWEL	PRODUCTION WELLS, NUMBER
39	INJWELL	INJECTION WELLS, NUMBER	40	SWZOS	SWEPT ZONE OIL SATURATION, PERCENT
41	INJSAL	INJECTION WATER SALINITY, PPM TDS	42	CLAY	CLAY CONTENT, PERCENT
43	DP OR VDP	DYKSTRA-PARSONS COEFFICIENT	44	INJRATE	CURRENT INJECTION RATE, B/D/WELL
45	FAULT	FRACTURED-FAULTED (Y,N) (N=0, Y=1)	46	SHALE	SHALE BREAK OR LAMINATIONS, (Y,N) (N=0, Y=1)
47	GASCAP	MAJOR GAS CAP, (Y,N) (N=0, Y=1)	48	FIELDMUL	FIELD MULTIPLIER, NUMBER
49	DISTRR	RRC DISTRICT	50	PRODRATE	PRODUCTION RATE FOR 1/1/79 , MBBL/D
51	LITH OR LIT	FORMATION LITHOLOGY, (1=SS,2=CARBONATE,3=MIXED)	52	MUW	USED INTERNALLY FOR WATER VISCOSITY
53	ER	USED INTERNALLY FOR RECOVERY EFFICIENCY			

TABLE 2. - Data dictionary for the fifth records of the BPO reservoir data

IN SITU COMBUSTION		STEAM DRIVE		GEOLOGICAL	
DARY NO.	DESCRIPTION	DARY NO.	DESCRIPTION	DARY NO.	DESCRIPTION
52	CLASS (ONGOING=1, FUTURE=2)	52	CLASS (ONGOING=1, FUTURE=2)	52	GEOLOGIC PLAY CODE
53	TOTAL DEVELOPED ACRES, ACRES	53	PRICING SCENARIO (1=LOW COST,2=AVG. COST,3=HIGH COST)	53	DEPOSITIONAL SYSTEM CODE
54	DEVELOPMENT YEARS, YEARS	54	DEVELOPMENT YEARS, YEARS	54	RESERVOIR FACIES CODE
55	COMPRESSOR FUEL (LEASE CRUDE=1, NAT. GAS=2 (DEFAULT))	55	FUEL TYPE (0=NAT. GAS, 1=LEASE CRUDE)	55	LATERAL HETEROGENEITY DESCRIPTION INDEX
56	AIR INJECTION RATE, MSCF/D	56	DEVELOPMENT ACRES, ACRES	56	VERTICAL HETEROGENEITY DESCRIPTION INDEX
57	MAX. VOLUME SWEPT, FRACTION	57	GENERATOR COST, $	57	BEG PROVINCE
58	COMPRESSOR COST, $/HP	58	GENERATOR FUEL RATING , BTU/UNIT	58	TRAP CODE
59	NO. INJECTORS DRILLED PER PATTERN	59	GROSS THICKNESS , FEET	59	PRIMARY DRIVE MECHANISM
60	NO. INJECTORS DRILLED PER PATTERN	60	INJECTION WELLS DRILLED PER PATTERN, NUMBER	60	CURRENT PRODUCTION TECHNIQUE
61	NET PAY, FEET	61	PRODUCING WELLS DRILLED PER PATTERN, NUMBER	61	DISCOVERY DATE
62	OIL PRICE, $/BBL	62	NATURAL GAS PRICE, $/MSCF	62	RATIO OF INITIAL GAS CAP VOLUME TO INITIAL OIL BANK VOLUME
63	FIXED OPERATING COST, $/PATTERN	63	GENERATOR FUEL PRICE, $/UNIT		
64	VARIABLE OPERATING COST, $/PATTERN	64	OPERATING COST, MM$		
65	COMPRESSOR OPERATING COST, $/KWHP	65	GENERATOR OPERATING COST, $/BBL		
66	TYPE FIREFLOOD (WET=1, DRY=2, DEFAULT=1)	66	PATTERN SPACING, ACRES/PATTERN		
67	CURRENT OIL SATURATION, PERCENT	67	STEAM RATE, BCWE/D/PATTERN		
68	PATTERN SPACING, ACRES				

Brief descriptions of each element in the first four records plus the geological data in the fifth record are given in Appendix A.

S2K Reservoir Data Base at EIA

One potential source of information for a reservoir data is the reservoir data base at Energy Information Administration (EIA). This data base has information on about 2,500 reservoirs and has 252 data fields. Besides the data, the data fields or elements in this database might be a starting point for a new DBMS. When this data base was developed, it was directed toward understanding reservoirs and not necessarily toward the EOR predictive models. Allowances were made for information on major secondary and tertiary projects.

S2K has a hierarchical record structure that is well suited for the field/reservoir data relationship and is shown in figure 2. The commercial DBMS's under consideration have relational record structures so the design for indices and structure will not translate well from S2K to the new DBMS. Although the hierarchical structure causes some differences in design concepts, the relationships and data groupings are appropriate for both systems.

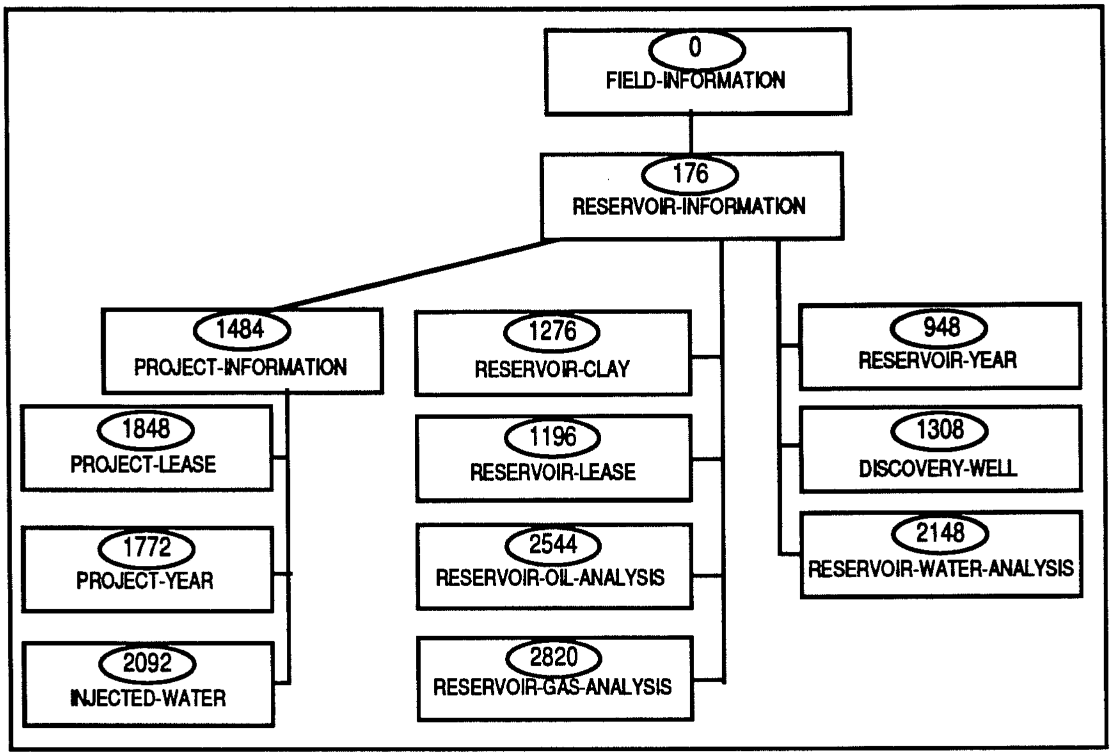

FIGURE 2. - Record structure for S2K reservoir data base at EIA.

One method of measuring the quantity of the information is to look at the frequency of information in each of the data fields. Figure 3 shows the frequency count, namely the number of entries, for each data field in the EIA version of the reservoir data base. Three data fields related to annual oil production distort this frequency distribution because they can have multiple entries for a single reservoir. Figure 4 is the frequency distribution of data fields after the annual production fields have been removed. Twenty data fields have over 85% representation, but representation rapidly drops in the remaining data fields. Only 31 data fields have over 50% representation. Over 100 have less than 5% representation.

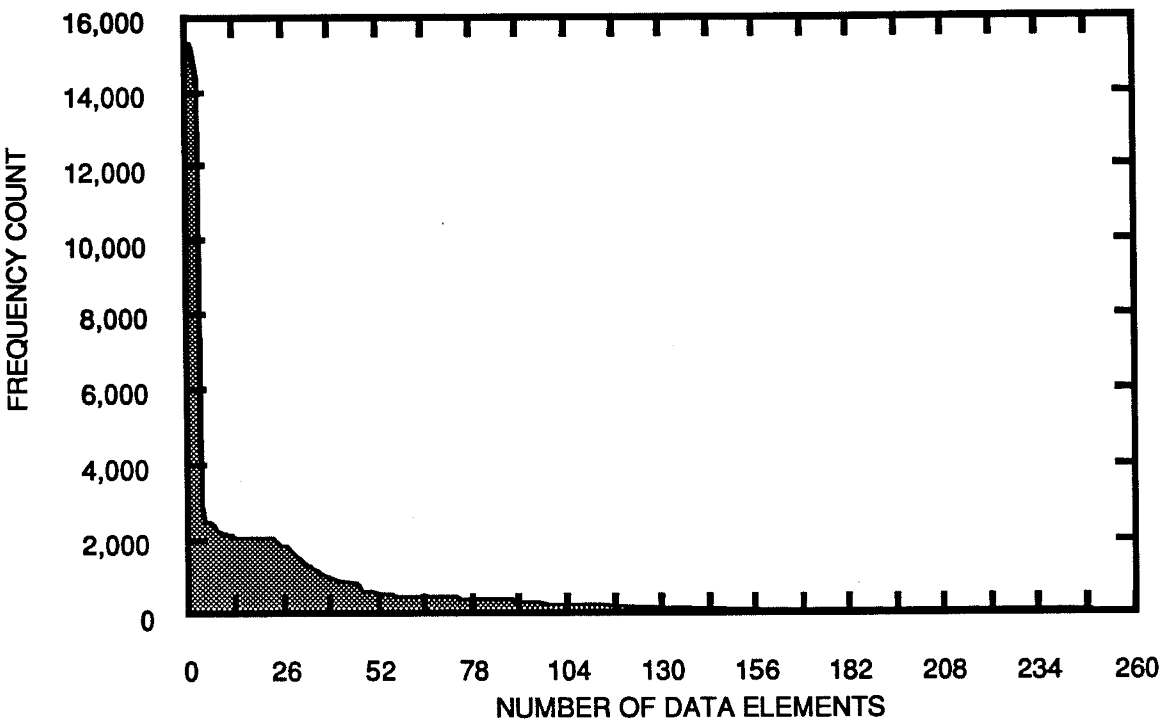

FIGURE 3. - Frequency of data in the data fields of the reservoir data base at EIA.

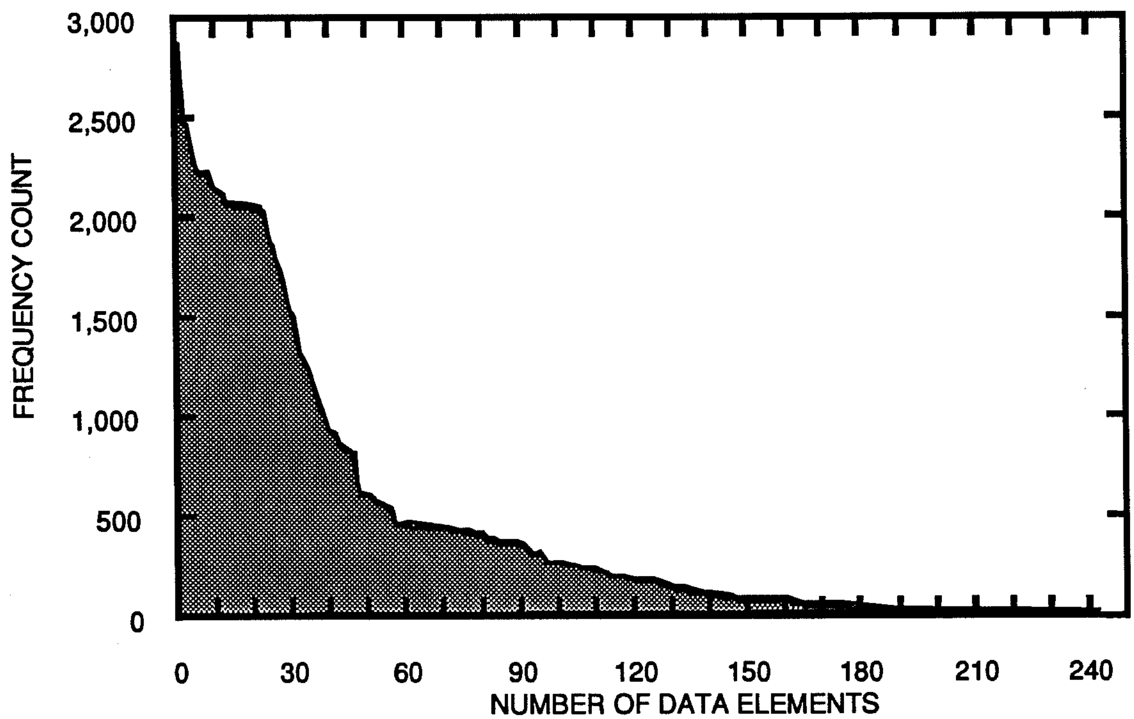

FIGURE 4. - Frequency of data in the data fields of the reservoir data base at EIA after eliminating the data fields with more than one occurrence per reservoir.

Table 3 is a list of the top data fields in the reservoir database at EIA. These well populated data fields are generally contained in the flat file database at BPO, except those relating to secondary and tertiary projects. Since there is a separate EOR project data base, there does not appear to be sufficient data in the other data fields to warrant an expansion of the BPO reservoir data dictionary base on the EIA reservoir data.

TABLE 3. - Top data fields in S2K version of the DOE reservoir data base

Data element	Frequency	Data element	Frequency
Reservoir year data source	15,309	Total wells, reservoir	1,869
Reservoir year	15,192	Reservoir production acres	1,856
Annual crude oil production	14,314	Ave. porosity	1,798
Cum. crude oil production	2,872	Ave. depth to top of pay	1,719
Reservoir source document	2,470	County code/pseudo code	1,678
Year reservoir discovered	2,469	Ave. permeability	1,536
Oil gravity (ave)	2,381	Reservoir trap type	1,528
Era system series, reservoir	2,255	Project initiated year	1,490
Net pay thickness	2,222	Initial water saturation	1,314
Reservoir lithology	2,212	Project method name	1,291
Project information source	2,136	Field formation name	1,242
Reservoir depth	2,123	Production well spacing, reservoir	1,197
Geologic age code-prod. formation	2,064	Project year	1,092
Reservoir production formation	2,058	Initial bottom hole temperature, °F	1,039
Field county	2,048	Primary drive mechanism	1,039
Field name	2,048	Current GOR	936
State/offshore name	2,048	Initial-oil-in-place	921
State postal code	2,048	Initial formation volume factor	919
Field code	2,047	Project lease operator name	863
Basin name	2,041	Current GOR year	842
Field basin code	2,039	Viscosity (Saybolt)	828
State code pseudo code	2,035	Injection wells, reservoir	820
Reservoir name	2,020		

Other Sources of Reservoir Data

There are numerous other sources of information on reservoirs. The commercial petroleum data bases available from Petroleum Information and Dwight's have been used to assist in analyzing collected data and have been the source of oil production information. The open literature is the other principal source. Reports from state geologic societies and thesis from universities have been used. Professional organizations, such as the Society of Petroleum Engineers and American Association of Petroleum Geologists, published technical papers in journals and proceedings of technical conferences. Oil Scouts reports have information on production and field/reservoir discoveries.

Reservoir Data Users

The principal user of the DOE reservoir data has been the DOE TORIS while conducting EOR predictive model studies. ICF/Lewin has been the support contractor that has assisted the TORIS program manager in conducting the studies. The use has been extensive in that it uses most of the data and all of the data elements in the BPO data files. This is expected to be a high priority user of the reservoir data. The recent addition of ten geological data elements expands this version to 61 data elements that are all important for conducting studies. This establishes the minimum data elements that must be maintained by the contemplated management system.

There have been other users of reservoir data that requested from DOE or NIPER statistical studies to indicate the magnitude of changes in oil production that might be affected by a particular technology or project that is under consideration. Other users of the reservoir data include the National Petroleum Council in its 1984 EOR study[1], major oil companies in screening their resource for EOR potential, and other companies screening the data for specific information to assist them in deciding about specific projects or products. Table 4 is a summary of users that have interest in reservoir data. These users are grouped by their type of access to the data. The first group, internal/direct, is users that might have direct access to the DBMS. The second group is users that will likely be requesting information through the DOE/BPO.

TABLE 4. - Some of the potential users of the DOE reservoir data

Internal/ direct users	Outside /indirect users
DOE TORIS	Major oil companies
DOE/BPO	Petroleum service companies
DOE, HQ, International Affairs	Independent oil companies
NIPER	Engineering consulting firms
DOE support contractors (ICF/Lewin)	Independent consultants
National Petroleum Council	Interstate Oil Compact Commission
	Oil related journals
	Financial institutions
	Chemical companies
	Data base developers
	Other government agencies
	State oil and gas commissions
	State geological surveys
	Educational institutions

USES OF RESERVOIR DATA BASE

The number of uses of the DOE reservoir data is changing. A primary use will continue to be TORIS modeling, but the new oil research implementation plan and related programs may become as important. As the existence of the data becomes widely known within the federal government, the public uses can be expected to expand. Each use has special needs that could be considered in the design, but the requirements of the models and the oil plan will be of primary concern.

The TORIS model is designed around the existing data management system. This use requires that the data be internally consistent and fit an input structure. Changes in the data need to be documented and checked for the effect on the model.

A major feature of the new oil research program is that research will be targeted toward self-similar reservoir classes. A classification system has been developed to assist in meeting this objective that is based on individual assessment of the depositional system, diagentic overprint, and structural compartmentalization for each of two lithologies. Figure 5 is a three-dimensional representation of the classification system for siliciclastic reservoirs with example fields put into the matrix. Appendix B is a brief description of the terms used in the geologic classification for both siliciclastic and carbonate reservoirs.

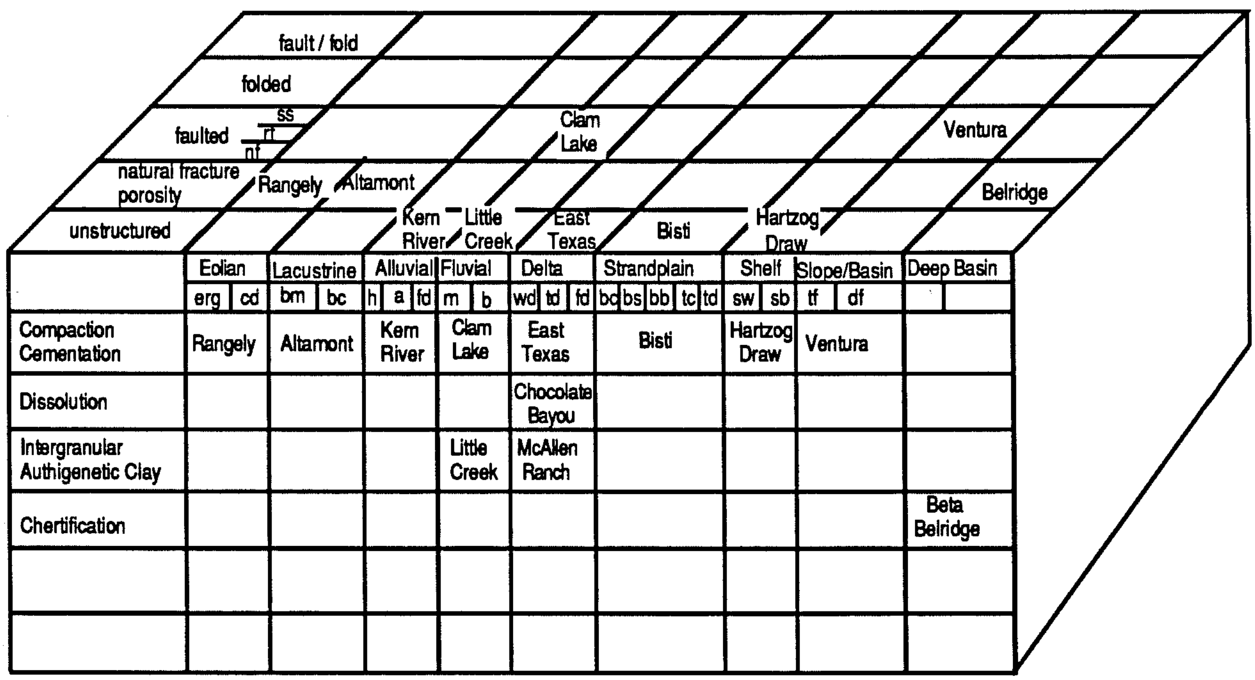

FIGURE 5. - Geological classification system developed for self-similar reservoirs.

The oil research plan will focus on research that is directed toward overcoming the technological barriers to applying advanced recovery technologies. The program will select 10 to 14 classes of reservoirs for special study. Class 1 and 2 reservoirs have been chosen for detailed study. A technical symposium on class 1 reservoirs, fluvial-domainated unstructured deltaic, was held January 1991.[5] Statistics of engineering parameters for oil pools within this class were presented which were obtained by an analysis of the DOE/BPO reservoir data. Class 2 will be shelf carbonate reservoirs.

The oil research plan calls for special demonstration projects within those reservoir classes that are targeted for special study. The DBMS will need to have provisions for the detailed data that might be used in analyzing these projects. Well data, seismic data, environmental data and site-specific geologic data might be obtained during the evaluation of a potential demonstration project. The storage, retrieval, and analysis of this data could be an important support function of the reservoir DBMS. To adequately support this use, there needs to be an ability to prepare maps and graphically display the data. This use has special software and hardware requirements.

An important consideration is the environmental sensitivity of the location of reservoirs and fields. The selection and consideration of the various classes of reservoirs will consider environmental factors. Factors such as whether the field is in a flood plain, a wilderness area, a high population area, or special habitat location are being obtained to help evaluate effects of environmental regulations and laws on the potential for petroleum production and EOR. Data on location of drinking water sources and the condition of both operating and abandoned wells have been obtained in various studies. These data could be added to assist in evaluation of environmental issues relating to petroleum production.

Table 5 lists some additional uses for reservoir data that have either occurred in the past or are likely to occur in the future.

An important part of the new oil research program is the transfer of technology to encourage effective application of EOR and advanced production techniques, and thereby increase domestic oil production. A 1980 survey[6] of the technology transfer requirements for EOR indicates the level of interest and potential use of reservoir information. Table 6 indicates the potential usage of reservoir data as it relates to EOR.

TABLE 5. - Potential uses of the information in a DOE reservoir data base

DOE program planning	Analysis of demonstration project
Computer simulations of reservoir performance	New NPC Reports
Black oil models	Resource Screening
EOR models	Resource Investment Reports
Material balance	Resource Profiles
Basin, Field, Reservoir, or State studies	Heavy oil profile
Annual production	Light oil profile
-- to evaluate the annual oil production based	Oil-field equipment needs
on regional parameters.	Reservoir water analysis
Incremental oil	Salinity studies
Oil-remaining	Clay content studies
Well-spacing	DOE Proprietary Uses
Occasional Requests	NIPER Proprietary Uses
Field inquiries	Comparison with other data
Reservoir inquiries	Statistical studies
State inquiries	Correlations of variables
Partial Validations of the NPC 1984 Study Report	Analysis of environmental impact

TABLE 6. - Usage level by user[6]

User	Usage High	Usage Medium	Usage Low
Major Integrated Producers	x		
Large Independent Producers	x		
Small Independent Producers		x	
Engineering Consulting Firms	x		
Oil Field Services		x	
Chemical Suppliers			x
Financial Institutions		x	
State Legislature			x
State Regulatory Agency		x	
Federal Policy Agency	x		
Educational Institution		x	
Environmental Agency			x

Typical Requests

The following are a few typical requests that were suggested by the 1980 technical transfer study.

Produce a list of candidate fields for: Heavy oil EOR using advanced technology, and Light oil EOR using thermal and advanced foam technology methods.

Produce a technical reservoir property screening guide to make a proposed technical evaluation of EOR reservoirs based on cost constraints supported by depth and reservoir acres found in the data base.

Make an evaluation of the known remaining oil resource in the State of Kansas.

The EPA wishes to obtain an abandoned well count for the State of Oklahoma.

Approximately 60% of oil producers say[6] that they require data on rock and fluid properties of a reservoir (or reservoir characteristics). About 14% need reservoir modeling, and 12 % need the production history. For reservoir characteristics, the priority of need as taken from the same DOE source is:

Characteristic	%
Oil-in-place	29
Unspecified characteristics	22
Porosity	17
Viscosity	10
Permeability	9
Residual oil saturation	8
Other	3

Conclusions of the Information Requirements Study

The principal source of information for the reservoir data base will be the flat file DOE/BPO reservoir data used for model studies. The S2K reservoir data will not be a significant addition to the data.

There are numerous uses and potential users of reservoir data. The principal use will continue to be the TORIS models, but the new oil research program will add numerous requirements for additional data, data storage, data retrieval, and analysis. The expanding needs include new information on geology and environment, as well as more reservoir data. A special consideration should be made for data generated by demonstration projects that are part of the new oil research program. This later item will require software and hardware capable of generating full size maps.

CONCEPTUAL DESIGN ISSUES FOR THE RESERVOIR DATA BASE

Some of the principal issues in design of a reservoir DBMS involve the expanding use of the data and the increasing number of users. The new oil research program adds new importance to depth of information in the data base beyond the data used by the TORIS model. The maintenance of confidentiality of sensitive and commercial data is a more difficult task. Hardware allowances for expanded availability is an issue because of special requirements of the existing BPO software and computer. Because the oil research program is dynamic, allowance for expansion of data elements is important. Optimizing the design for operation and system maintenance are important considerations. These conceptual issues have numerous alternatives, so the purpose of this study is to narrow the number of alternatives that might be included in the final design.

At present, design considerations are limited to the current BPO computer (Concurrent) and software (RELIANCE). Because the RELIANCE software is based on the relational model, most of the concepts will transfer to other relational data management software.

Special Features of RELIANCE

The RELIANCE software has numerous features that make it suited to the needs of the reservoir DBMS. It is a data management framework designed to operate on Concurrent computers. Its strength is in online transactions processing and retrieving related data. It is a collection of software routines which allows development of a tailored DBMS for a specific implementation. The implementation of the DBMS can evolve from data storage files with primary keys and secondary keys with elementary retrievals to a very complex, tightly managed system of applications for data addition and retrievals. An implementation is developed by building data definition and screen formats interactively. Application programs using either RELIANCE subroutines, RELIANCE Builder, or those written in FORTRAN VII, COBOL, or C languages are used to control transactions (messages between the terminal and the computer). The transactions can range from a simple retrieval of data elements to a complex Boolean search of up to four data files at once. The DOE BPO is currently using the system to manage data on EOR projects.

AVAILABILITY

One area of concern for a new data management system for the petroleum reservoir information that has been collected by the TORIS program is its availability or accessibility to the public. The alternatives for providing this availability are (1) to maintain two databases, one for the public and one for internal DOE studies, or (2) to have one database in RELIANCE that controls public access to non-proprietary data as well as control the access to the use of the BPO computer. Both alternatives have advantages. One of the objectives of this study is to determine the technical feasibility of both of these alternatives.

One of the requirements for using the RELIANCE database management system (DBMS) is a 6312 Concurrent computer terminal. This terminal has special communication protocols around which RELIANCE was developed. An additional problem is that the Concurrent operating system does not allow access to RELIANCE through a modem. One area of research was to identify options that solve these limitations and to test the options to determine if an alternative of open access to a RELIANCE version of a reservoir database is feasible.

Three different IBM PC compatible terminal emulator software packages were identified that reportedly were commercially available and would emulate a 6312 Concurrent terminal. Additional research determined that only one of these packages was commercially available – PC Passport. This terminal emulator was used in the daily work with the RELIANCE version of the EOR project database as part of another project. The IBM AT compatible is directly connected to the BPO Concurrent computer operating at 9,600 Baud. This software is solid in that problems that related to the software during the test period did not appear.

The ability to interface with the integrated transaction controller (ITC) of RELIANCE and the Concurrent operating system (OS/32) is facilitated by the use of a telecommunication package available from Stuart Barker Inc. called Passport. Passport on the BPO computer allows modem communications with ITC of RELIANCE as well as features for telecommunications and security control for outside modem connections. Installation of a Passport demonstration package required a correction to the integrated terminal access method (ITAM) device statements that are used in the system sysgen routines. After the initial installation problems were resolved, the RELIANCE related features and the XMODEM32 communications features were tested. Passport and Passport PC were demonstrated by accessing RELIANCE based databases from a IBM PC via a telephone modem and that access could be limited to RELIANCE. The use of RELIANCE Builder routines can limit the access of any user to specific portions of the DBMS and not allow access to the computer. Another feature of interest to BPO was the XMODEM32 capabilities. XMODEM is a communications protocol that has an error checking feature to prevent an inaccurate transmission of data.

The combination of Passport and PC-Passport would allow access to a reservoir data base on the BPO computer by authorized personnel from a PC. This provides direct availability to the data without requiring special equipment or direct linkage to the BPO computer.

SECURITY AND ACCESS CONTROL

The RELIANCE system has extensive capabilities to limit the availability of data and DBMS features to specific users. This feature presents an infinite number of possible alternatives for maintaining security and confidentiality of data. The preferred alternative is to base authorization on the type of user and the need-to-know requirements of those users.

The following is a conceptual alterative that meets the requirements for security and access control consistent with the information requirements study. The concept is defined as structure of authorization passes that control access to sensitive data and data management features. Other special DOE/NPC information regarding their sources and confidentiality of the reservoir data could be used to allow special access to providers of information.

Security will be on a non-distributed RELIANCE system using a single ITC environment, and will be controlled by a RELIANCE expert. All authorization passes, aliases, data protection, access rights, and function security will be under a Security Controller. The Security Controller can impart all or part of the security burden to anyone else. A user may have one or more authorization passes depending on the the functions he is performing. The RELIANCE process of auto-allocation allows all passes listed to the user to be allocated to the user's authorization pass. This enables an authorization hierarchy to be set up.

Potential users of the reservoir data can be classified in five groups for security and access purposes. These are the security controller, data base developers, data management, users doing proprietary research, and users doing non-proprietary searches or reports. Table 7 summarizes the activities in which each of these user groups would be involved. A hierarchy of 11 authorization passes was used to give each of the users an appropriate amount of access to the possible RELIANCE activity and data. The P1 to P11 shows the authorization of each user for each activity. A definition of the user group is included in the table.

TABLE 7. - Appropriate authorization for user grouping versus RELIANCE activity

RELIANCE ACTIVITY	Security Controller	TORIS Developers	TORIS DB Management	Official Proprietary Research	General Public
Control all security	P1				
Application development using BUILDER	P2	P2			
Application development using C, FORTRAN, & Cobol	P3	P3			
Create & Maintain Update & Profile Transactions	P4	P4			
Run Update Transactions (Enter & modify data)	P5	P5	P5		
Modify Dataviews	P6	P6			
Create Sensitive Dataviews	P7	P7		P7	
Create ITC Support screens	P8	P8			
Use ITC Support screens	P9	P9	P9	P9	P9
Authorized Retrieval of sensitive data	P10	P10	P10	P10	
Public Data Retrieval	P11	P11	P11	P11	P11
Pass Group	G1	G2	G3	G4	G5

Security Controller - will have control over overall security activities, authorizations, and protections of critical database objects and their functions; also all construction of BUILDER applications for later use by authorized users. Close support of BPO management goals will be maintained.

TORIS Developers - will be responsible for creating the tools and utilities needed to fill and maintain the data base and to construct special applications and sensitive queries needed to sort, select, and retrieve information from the database under their respective security levels, as given by the Security Controller. Guidelines for the development will be supplied by the BPO management.

TORIS DB Management - will be in charge of entering, validating, and maintaining informations and data in the TORIS data base, through the use of applications and utilities issued by the Security Controller under the proper authorization. Information planning will follow BPO authorized plans.

Official Proprietary Research - will be permitted access, select, and retrieve DB information which is considered to be proprietary and well as public, under official BPO guidelines.

General Public - public information in the data base available for a retrieval process to be determined by the BPO management.

Another way of assigning authorization is to look at the function within each of the objects used by a user. Table 8 shows the appropriate assignment of authorization level to the object-function combination. The grant and withdraw function refers to the ability to restrict or extend access to the screen in a controlled fashion, to allow other passes to share some or all of the access rights which grantors passes carry. Control security refers to the right to add or remove all protection from an object. The pass level (P1 to P11) corresponds to those in table 7.

TABLE 8. - Appropriate authorization for each function of an object activity

	Function Group								
Reliance Objects	Run	Maintain	Grant/ Withdraw	Control Security	Use	Open	Update	Log Delete Record	Create MTM-acct. ITC Users
APPLICATIONS									
Builder	P5	P2	P2	P1	-	-	-	-	-
C,Cobol,FORTRAN	-	P3	P2	P2	P1	-	-	-	-
Dataviews									
sensitive	-	P6	P7	P1	-	P10	P5	-	-
public	-	P6	P7	P1	-	P11	P5	-	-
DMS files									
sensitive	-	P4	P4	P1	-	P10	P5	-	-
public	-	P4	P4	P1	-	P11	P5	-	-
DSS task	-	-	P1	P1	-	-	-	-	P1
User pass	-	P1	P1	P1	-	-	-	-	-
REPORTER/32									
(format and group)									
sensitive	P10	P4	P4	P1	-	-	-	-	-
public	P11	P4	P4	P2	-	-	-	-	-
RUS/32 Profile Updates	P5	P4	P4	P1	-	-	-	P4	-
RUS/32 Profile Read Only									
sensitive	P10	P4	P4	P1	-	-	-	P4	-
public	P11	P4	P4	P1	-	-	-	P4	-
Application									
RQL/32 Saved Queries	P10	P4	P4	P1	-	-	-	-	-
sensitive	P11	P4	P4	P1	-	-	-	-	-
public									
ITC Screen forms	-	P9	P4	P1	P8	-	-	-	-

This security access is controlled through the distributed security system (DSS). A default set of security features exists consisting of a signon password for an authorized user, a restriction made by the initial user menu, and a restriction made by the dataviews allowed on certain selected fields or DMS files. The RELIANCE Builder feature can be used to control the features that are available to each user. However, if SUPPORT, DATADEFN, or QUERY features are present, only the signon password is the restriction and the knowledge of the user to use the features.

A good "rule-of-thumb" to follow is that if the data are sensitive or proprietary in nature, then the file should be registered under DSS and be protected, rather than the transaction to the data.

Information Source for Data

As information is added to a technical data base such as the reservoir data base, conflicts will arise as to the quality or appropriateness of the data. New information will be received that appears to contradict what is in the data base. Unless there is a good referencing tool within the data base, assessing the quality of the existing data is difficult to determine. The current data uses a matrix of reference numbers that indicates which contractor supplied the data. Since the number of sources of information is expected to expand, this method needs to be refined to meet the expanded needs.

The new design would continue and expand the referencing system in current use. A separate reference DMS file would have a complete, detailed reference of all the sources of data for each data element that might come into conflict.

File Structure

To manage data in a relational data model such as that using RELIANCE or dBase, relational integrity must be maintained. RELIANCE and dBASE IV lack automatic methods for maintaining relational integrity. The programmer must write applications to maintain database integrity. However, prior to relational integrity, the database must be in "third normal form". This is accomplished in the design process and optimizing the data structures. First normal form eliminates repeating data elements from the structure of the file. The data can now be visualized as a table, or more precisely as a two-dimensional array. Second normal form files have primary keys created from the concatenation of secondary or foreign keys. The data tables are analyzed for relationships of each data element to the primary key. Second normal form requires that all data elements in the file must be dependent on the complete primary key. Third normal form eliminates transitive dependencies. Transitive dependence is exemplified by a non-key data element that is dependent upon any other data element or elements excluding the primary key. These considerations and techniques are widely documented.[8-11]

After the process of normalization has been completed and any exceptions documented, the programmer must write applications that protect the entity integrity (primary key integrity) and referential integrity (secondary key integrity). Each primary key of a record must be unique. This makes each record in a file identifiable by its primary key. Therefore, the following rule ensures entity integrity. The value of a primary key must not be changed to the same value of another primary key in the same file and the primary key must be valued (not null). Referential integrity ensures that a relational data base can identify related records within different files. Applications need to be written for the editing, appending, or deleting of records that check for the validity of foreign and primary key values and relations. Tom Kemm[12] fully discusses the concept of relational integrity.

There are numerous considerations for optimizing the file structure in addition to the data base management considerations discussed above. The priorities for the competing features were identified in the information requirement study. One of the complicating factors is to support the complicated needs of TORIS modeling studies while supporting access to measured data on individual reservoirs. Some data are acquired from commercial data bases and can not legally be made public. Other information has been acquired from petroleum companies with the understanding that the information is proprietary. Much of the information has been accumulated from public sources in government funded studies and duplicates some of the information from proprietary sources. The system has to safeguard proprietary information from improper dissemination while allowing public access to that data gathered for public use. The file structure, security system, special application programs, and special codes within the data dictionary can be used to accomplish this diverse set of requirements.

One of the unique requirements of the modeling is the assignment of oil production data to reservoirs. Since oil production is sometimes co-mingled from all producing reservoirs within an oil field, the oil production data are available only for fields and not specific reservoirs. Although attempts can be made to estimate the production from each reservoir, sometimes it is just as accurate for the modelling to adjust some of the reservoir parameters to a pseudo-reservoir or model-sensitive-reservoir that reflects the economics and production potential of EOR in a particular field or for a group of similar reservoirs. The current reservoir data files have some model-sensitive reservoirs or geologic plays.

Both the model-sensitive and proprietary-sensitive data need to be considered in the final design. The current concept is to treat these two problems similarly by using a code data element in the dictionary that an application program or RELIANCE query can use to insure that the specific user obtains the appropriate data without duplication.

Sensitive reservoirs may be appropriate for computer model studies or for statistical analysis if the development of the model-sensitive-reservoir data is understood. For those users of the reservoir data that do not have this sophistication or are interested in a specific reservoir, the model-sensitive data might appear to be an error in the database. Therefore, an accommodation for both nonsensitive reservoir data and model-sensitive reservoir data is desirable. There are two basic alternatives for handling this trade-off that use both primary and secondary keys. One alternative method would put all the nonsensitive-data reservoirs in one DMS file and link the nonsensitive reservoirs to sensitive reservoirs in another DMS. A code data element in the dictionary that indicates which non-sensitive reservoirs have a corresponding sensitive-reservoir and would allow a knowledgeable operator to query the nonsensitive reservoirs and sensitive reservoirs without including the nonsensitive reservoirs represented in the sensitive-reservoirs. Applications programs and predefined queries could be written to eliminate the possibility of retrieval errors.

The other method would put the nonsensitive reservoirs that are part of sensitive reservoirs used in model studies in another DMS with a one to many relationship. A code data element in the data dictionary would be used to indicate which reservoirs were nonsensitive and which were sensitive. This method has an advantage since the main source of data is the data files used for reservoir model studies. Nonsensitive reservoirs that have associated sensitive reservoirs have not been removed from the data files, but their data have not been subjected to the high review standards applied to other reservoir data. The relational integrity of the production data will be easier to maintain with this file structure alternative. Properly written application programs would keep each user from accessing inappropriate data.

Either of these methods could be made transparent to the user by application programs. Figure 6 is an illustration of the user interfaces with the data files and a summary of the conceptual file structure.

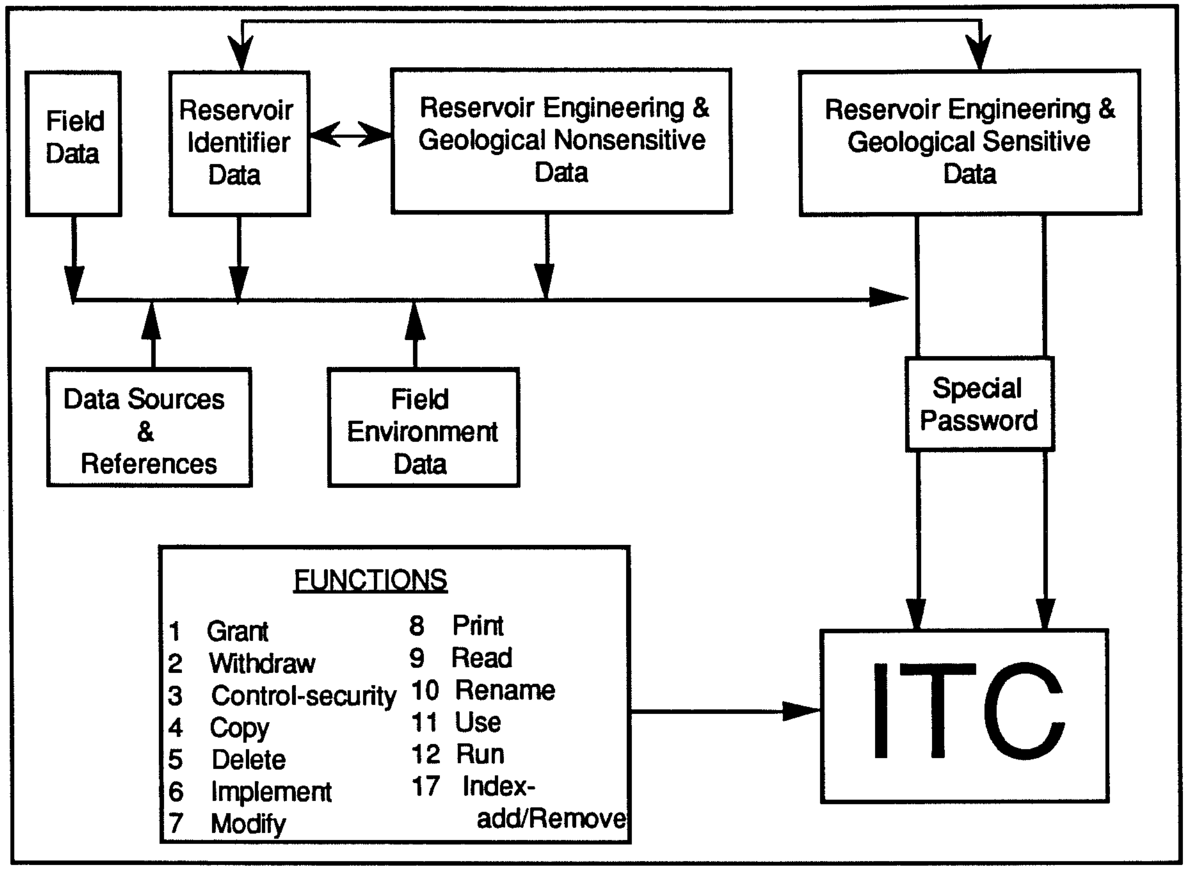

FIGURE 6. - Summary of the conceptual design.

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APPENDIX A

GLOSSARY FOR TERMS IN DOE FLAT FILE RESERVOIR DATA

RECORD 1

Field Code - A unique six digit figure number assigned to each field name by the Energy Information Agency, DOE. Note: number is only as unique as field name, i.e. when there is more than one field with the same name, the field code number will be the same.

State postal code - The unique two character code assigned to each state by the United States Post Office.

Lithology code - A single digit code assigned to each reservoir so they could be assigned to practical EOR processes. Originally 0 was unknown, 1 was sandstone and 2 was carbonate; later 2 was limited to limestone, and 3 was dolomite. Note: highly calcareous sand was usually included with limestones.

Geologic age code - A three-digit code for the geologic age of the producing formation based on numbers assigned by the American Association of Petroleum Geologists (AAPG) to each geologic strata.

Field name - Name assigned to an area of one or more oil or gas reservoirs all grouped on or related to the same individual geological feature and approved by the state agency responsible for petroleum production. Note the form of the name used is that used by EIA in the field code master list. Unless directions are part of a formal name like East Texas they are not used as the first name of a field, i.e. East Columbia and West Columbia become Columbia East and Columbia West. If names exceed 26 characters, directions are abbreviated, i.e. N for north, NE for northeast, etc.

Reservoir name - Name assigned (usually by a state regulatory agency) to a continuous pool of oil separated by impermeable layers or water to form a pressure system. Pool name is usually the same.

Reference number - A unique number assigned to each reservoir at the time it is added to the database. Usually tells when a reservoir was added and who or which group added it.

Load number - Item number or position of the reservoir in an alphabetical (by state code,field name,and formation name) listing of reservoirs.

Formation name - Name assigned to the producing geologic stratum that makes up the reservoir. Often the same as the reservoir name.

RECORD 2

Field acres - Surface area of the oil and/or gas field in acres. Probably larger than individual reservoirs and may include nonproductive wells.

Proven acres - Surface area (acres) of the field that is known (wells have been drilled and oil produced from them) to contain oil that can be produced using techniques currently being used in the field.

Well spacing - Surface area in acres that producing wells in the same reservoir produce from, usually assigned by the state or other governmental authority. Note: If more than one spacing is used, then the one covering the largest area is recorded.

Total wells - Total number of active wells in the field. Usually the sum of production and injection wells.

Net pay - Thickness in feet of the portion of the producing formation that is actually producing oil.

Gross pay - Thickness in feet from the top to the bottom of the oil producing zone.

Porosity - Percent of the producing formation that is not rock(solid mineral).

Initial oil saturation - Percent of the pore space in the oil-containing portion of the producing formation that was oil when the reservoir was discovered.

Current oil saturation - Percent of the pore space in the oil containing portion of the producing formation that currently contains oil.

Initial water saturation - Percent of the pore space in the oil containing portion of the producing formation that was water when the reservoir was discovered.

Current water saturation - Percent of the pore space in the oil containing portion of the producing formation that currently contains water.

Initial gas saturation - Percent of the pore space in the oil containing portion of the producing formation that was gas when the reservoir was discovered.

Current gas saturation - Percent of the pore space in the oil containing portion of the producing formation that currently contains gas.

Initial oil FVF - Oil formation volume factor at the time the reservoir was discovered. Oil formation volume factor is the ratio of the volume of a barrel of oil in the reservoir to the volume of the same barrel at surface conditions (called a stock tank barrel).

Current oil FVF - Oil formation volume factor at the present time. Oil formation volume factor is the ratio of the volume of a barrel of oil in the reservoir to the volume of the same barrel at surface conditions (called a stock tank barrel).

True vertical depth - Usually the depth from the surface to the top of the producing zone or top perforation into the producing zone, however it says mid perforation so I assume that's what they mean.

Formation temperature - Current temperature in degrees Fahrenheit of the oil producing zone.

RECORD 3

Current formation pressure - Pressure in psi presently exerted in the wellbore at the oil producing zone face by the fluids in the formation.

Permeability - Ability of the reservoir rock to transmit fluids in millidarcies usually measured on a dry core with air as the fluid. Permeability in millidarcies is calculated by multiplying 1,000 times the flow rate in cm^3/sec times fluid viscosity in centipoise times core length in cm divided by area of the core in square centimeters times the pressure drop across the core in atmospheres.

Geologic age - A three digit code assigned by the AAPG to each geologic age group.

API gravity - The standard adopted by the American Petroleum Institute (API) for measuring the specific gravity (density) in units of degrees API which is equal 141.5 divided by the specific gravity then subtracting 131.5. Usual range is 10 (density of water) to 40 (light like fuel oil). Note: A potential source of trouble is the fact that API gravity can be negative (a -2 is in the database).

Oil viscosity - A measure of how easily reservoir oil will flow at reservoir conditions in units of centipoise. Molasses is an example of a liquid with very high viscosity and gasoline is an example of very low viscosity.

Formation salinity - The concentration in parts per million of total dissolved solids in the water in the oil producing portion of the reservoir.

OOIP - Original (at the time of discovery) oil-in-place in the reservoir in stock tank barrels. Usually calculated by multiplying 7,758 times the reservoir area in acres times the average net pay in feet times porosity times initial oil saturation divided by oil formation volume factor.

Primary recovery factor - The fraction of OOIP recovered or predicted to be recovered using the energy originally present in the reservoir. Usually includes gas-cap drive, solution-gas drive, natural water drive, or a combination of these.

Secondary recovery factor - The fraction of OOIP recovered or predicted to be recovered by waterflooding the reservoir.

Cumulative oil production - Total stock tank barrels of oil produced from the reservoir as of the end of a stated year.

Year for cumulative oil production - Supposed to be 4 digit year for final year in cumulative oil production, however instead of 19 the first 2 digits sometimes represent month to which oil is totaled.

Technical availability date - Year in which the reservoir is realistically predicted to be available for EOR production.

Primary recovery (BBL/ACFT) - Barrels of oil per acre-foot recovered or predicted to be recovered using the energy originally present in the reservoir.

Primary recovery (BBL) - Total barrels of oil recovered or predicted to be recovered using the energy originally present in the reservoir.

Year for primary recovery - Four digit year primary oil was or is predicted to be recovered.

Current producing GOR - Present gas to oil ratio for produced fluids. Year should be the same as that for cumulative recovery.

Initial producing GOR - Gas to oil ratio for produced fluids at the time the reservoir was discovered. Sometimes called solution gas oil ratio at the time of discovery.

RECORD 4

Reservoir acreage - Surface area of the oil reservoir in acres.

Initial formation pressure - Fluid pressure in pounds per square inch in the reservoir at the time of discovery. Measured by shutting the well in either at the bottom of the hole or at the surface then corrected for weight of fluids in the wellbore.

Reservoir dip - Angle in degrees from the horizontal plane that is the major slope for the top of the oil reservoir.

Production wells - The number of wells in the reservoir producing oil. The year for this should be the same as for cumulative recovery which should be as close to current as possible.

Injection wells - The number of wells in the reservoir where fluid is being injected for the production of oil. The year for this should be the same as for cumulative recovery which should be as close to current as possible.

Swept zone oil saturation - Percent of reservoir porosity containing oil after being waterflooded

Injection water salinity - The concentration in parts per million of total dissolved solids in the water being injected into the reservoir.

Clay content - The percent of the rock portion of the reservoir that is clay.

Dykstra-Parsons coefficient - A measure of reservoir heterogeneity based on permeability variation. Calculated by subtracting the permeability one standard deviation below the normal from the normal permeability and dividing by the normal permeability. Normal permeability is the permeability that half the measured permeabilities are greater than. The permeability that is one standard deviation below normal is that permeability that 84.1 percent of the measured permeabilities are greater than.

Current injection rate - Volume of fluid in barrels that are being injected into the reservoir each day divided by the number of injection wells. Usually the average for the last month or longer.

Fractured-fault - Code of 1 if the reservoir is significantly broken up by fractures and/or faults, 0 if it isn't, and -1 if not known.

Shale break or laminations - Code of 1 if the reservoir contains a significant number of shale breaks or laminations, 0 if it doesn't, and -1 if not known.

Major gas cap - Code of 1 if the reservoir has a significant volume of free gas (major gas cap), 0 if not, and -1 if not known.

Field multiplier - Originally the number (decimal) of fields with similar characteristics that the person or company supplying the data knew about. Since this could lead to duplication the number is not thought to be used.

RRC district - In Texas the number of the railroad commission district times ten plus 1 if A, 2 if B, etc. A similar technique was used for other states which were separated into districts or other distinct areas. See table 1.

Production rate - Rate at which oil was produced in thousands of barrels per day. Usually the average for the last year in the cumulative production total.

Recovery efficiency-waterflood - Ultimate recovery factor for the reservoir (primary plus secondary). Fraction of the original oil in place that will have been recovered after the reservoir has been waterflooded.

GEOLOGIC RECORD 5

Geologic play code - An up to four digits number assigned to each of the geologic plays that produce oil.

Depositional system - A three digit code for the specific type of system that produced the reservoir rock. .

Depositional system degree of confidence - Code for reliability of depositional system data where 1 is highest, 2 is moderate, and 3 is lowest.

Diagenic Overprint Code - Up to two digit code for most important changes made in the reservoir rock after it was first laid down.

Diagenic Overprint Code degree of confidence - Code for reliability of diagenic overprint data where 1 is highest, 2 is moderate, and 3 is lowest.

Structural Compartmentalization - Up to two digit code for the degree of compartmentalization (breaking up of the reservoir into pieces that act in a semi independent manner such as lenses or blocks).

Structural Compartmentalization degree of confidence - Code for reliability of structural compartmentalization data where 1 is highest, 2 is moderate, and 3 is lowest.

Predominant element of reservoir heterogeneity - One digit code for the major cause of reservoir heterogeneity with 1 representing depositional system, 2 diagenic overprint, and 3 structural compartmentalization.

Trap type - One digit code for the kind of geologic structure that forms the oil reservoir where 1 is stratigraphic, 2 is structural, and three is a combination.

Geologic province - Three digit code (USGS) for the geologically defined area such as basin, uplift, etc. where the reservoir is located.

TABLE A-1. - State Regulatory Districts (RRC district)

STATE	CODE	DISTRICT NAME	COUNTIES [1]
Arkansas	1	North	Cleburne, Conway, Crawford, Franklin, Johnson, Logan, Madison, Scott, Sebastian, Washington, and Yell
	2	South	Ashley, Bradley, Calhoun, Columbia, Hempstead, Lafayette, Miller, Nevada, Quachita, and Union
California	1	Long Beach	Los Angeles (except NW corner), San Bernardino, Orange, Riverside, San Diego, and Imperial
	2	Ventura	Ventura and NW corner of Los Angeles
	3	Santa Maria	Santa Barbara, San Luis Obispo, Monterey, Santa Cruz, and Santa Clara
	4	Bakersfield	Kern, Tulare, and Inyo
	5	Coalinga	Kings, Fresno, San Benito, and Merced
	6	Woodland	No oil fields only gas
Louisiana	50	North	Avoyelles, Bienville, Bossier, Caddo, Caldwell, Catahoula, Claiborne, Concordia, De Soto, East Carroll, Franklin, Grant, Jackson, La Salle, Lincoln, Madison, Morehouse, Natchitoches, Quachita, Rapides, Red River, Richland, Sabine, Texas, Union, Vernon, Webster, and Winn
	10	South	Acadia, Allen, Ascension, Assumption, Avoyelles, Beauregard, Calcasieu, Cameron,Catahoula, East Baton Rouge, East Feliciana, Evangeline, Iberia, Iberville, Jefferson, Jefferson Davis, Lafayette, La Fourche, Livingston, Orleans, Plaquemines, Pointe Coupee, Rapides, St. Bernard, St. Charles, St. Helena, St. James, St. John The Baptist, St. Landry, St. Martin, St. Mary, St. Tammany, Tangipahoa, Terrebonne, Washington, West Baton Rouge, West Feliciana
	05	State offshore	
	00	Federal offshore	
New Mexico	10	East	Chaves, Eddy, Guadalupe, Lea, Roosevelt
	50	West	Luna, McKinley, Mora, Rio Arriba, San Jaun, and Sandoval

TABLE A-1. - State Regulatory Districts (Continued)

STATE	CODE	DISTRICT NAME	COUNTIES [1]
Oklahoma	1	Central	Lincoln, Pawnee, and Payne
	2	Creek	Creek
	3	East Central	McIntosh, Muskogee, Okfuskee, Okmulgee, Sequoyah, Tulsa, and Wagoner
	4	Northeast	Craig, Mayes, Nowata, Ottawa, Washington
	5	Northern	Canadian, Garfield, Grant, Kay, Kingfisher, Logan, and Noble
	6	Oklahoma City	Cleveland and Oklahoma
	7	Osage	Osage
	8	Panhandle NW	Alfalfa, Beaver, Blaine, Cimarron, Custer, Dewey, Ellis, Major, Roger Mills, Texas, Woods, and Woodward
	9	Seminole	Hughes, Pottawatomie, and Seminole
	10	South Central	Carter, Garvin, Love, McClain, Murray,
	11	Southeast	Atoka, Bryan, Coal, Haskell, Le Flore, Marshall, McCurtain, Pittsburg, Pontotoc, and Pushmataha
	12	Southwest	Beckam, Caddo, Comanche, Cotton, Grady, Greer, Jackson, Jefferson, Kiowa, Stephens, Tillman, and Washita
Texas	10	1	Atascosa, Bandera, Bastrop, Bell, Bexar, Blanco, Burnet, Caldwell, Comal, Dimmit, Edwards, Frio, Gillespie, Gonzales, Guadalupe, Hays, Kendall, Kerr, Kinney, La Salle, Llano, McMullen, Mason, Maverick, Medina, Milam, Real, Travis, Uvalde, Val Verde, Williamson, Wilson, and Zavala
	20	2	Bee, Calhoun, De Witt, Goliad, Jackson, Karnes, Lavaca, Live Oak, Refugio, and Victoria
	30	3	Austin, Brazoria, Brazos, Burleson, Chambers, Colorado, Fayette, Fort Bend, Galveston, Grimes, Hardin, Harris, Jasper, Jefferson, Lee, Liberty, Madison, Matagora, Montgomery, Newton, Orange, Polk, San Jacinto, Trinity, Tyler, Walker, Waller, Washington, and Wharton
	40	4	Aransas, Brooks, Cameron, Duval, Hidalgo, Jim Hogg, Jim Wells, Kennedy, Kleberg, Nueces, San Patricio, Starr, Webb, Willacy, and Zapata
	50	5	Bosque, Collin, Dallas, Delta, Ellis, Falls, Fannin, Freestone, Henderson, Hill, Hopkins, Hunt, Johnson, Kaufman, Lamar, Leon, Limestone, McLennan, Navarro, Rains, Robertson, Rockwall, Tarrant, and Van Zandt

TABLE A-1. - State Regulatory Districts (Continued)

STATE	CODE	DISTRICT NAME	COUNTIES [1]
	60	6	Anderson, Angelina, Bowie, Camp, Cass, Cherokee, Franklin, Gregg, Harrison, Houston, Marion, Morris, Nacogdoches, Panola, Red River, Rusk, Sabine, San Augustine, Shelby, Smith, Titus, Upshur, and Wood
	65	6E	(East Texas Field)
	72	7B	Brown, Callahan, Coleman, Comanche, Coryell, Eastland, Erath, Fisher, Hamilton, Haskell, Hood, Jones, Lampasas, Mills, Nolan, Palo Pinto, Parker, San Saba, Shackelford, Somervell, Stephens, Stonewall, Taylor, Throckmorton,
	73	7C	Coke, Concho, Crockett, Irion, Kimble, McCulloch, Menard, Reagan, Runnels, Schleicher, Sutton, Terrell, Tom Green, and Upton
	80	8	Andrews, Brewster, Cochran, Crane, Culberson, Ector, El Paso, Glasscock, Howard, Hudspeth, Jeff Davis, Loving, Martin, Midland, Mitchell, Pecos, Presidio, Reeves, Sterling, Ward, Wharton, and Winkler
	81	8A	Bailey, Borden, Cottle, Crosby, Dawson, Dickens, Floyd, Gaines, Garza, Hale, Hockley, Kent, King, Lamb, Lubbock, Lynn, Motley, Terry, and Yoakum
	90	9	Archer, Baylor, Clay, Cooke, Denton, Foard, Grayson, Hardeman, Jack, Knox, Montague, Wichita, Wilbarger, Wise, and Young
	100	10	Armstrong, Briscoe, Carson, Castro, Childress, Collingsworth, Dallam, Deaf Smith, Donley, Gray, Hall, Handsford, Hartley, Hemphill, Hutchinson, Lipscomb, Moore, Ochiltree, Oldham, Parmer,Potter, Randall, Roberts, Sherman, Swisher, and Wheeler

[1]Counties with no oil production may not be listed.

APPENDIX B

EXPLANATION OF TERMS IN GEOLOGICAL CLASSIFICATION

A description of the classification system that will be used to implement the new oil research program is in "Reservoir Heterogeneity Classification System For Characterization and Analysis of Oil Resource Base in Known Reservoirs".[4] The following is a brief description or explanation of the terms used by the classification system.

CARBONATE DEPOSITIONAL SYSTEM

1 Lacustrine - Deposited in a lake environment. Rare for a carbonate reservoir, but fractured carbonates of the Green River formation produce in the Uinta Basin in Utah.

2 Peritidal - Deposited in and/or next to tidal flats. Supratidal is above the tidal flats and subtidal is below. Most oil production is from the subtidal bars and beaches, but most reservoirs contain both supratidal and subtidal elements. Examples are San Andres reservoirs of the Slaughter and Leveland fields in the Permian Basin and the Red River reservoir in the Williston Basin.

3 Shelf - Facies deposited on a broad carbonate platform in the off shore marine environment. Examples are the San Andres reservoir in Wasson field in the Permian Basin and the Mississippian reservoir in Mondak field in the Williston Basin. Open shelf and restricted shelf are subcategories.

4 Shelf edge - Deposited along the outer edge of carbonate platforms or ramps. Examples are the Grayburg reservoirs of the Dune and McElroy fields at the edge of the Central Basin Platform. Rimmed shelf and ramp are subcategories.

5 Reef - An undersea ridge of coral or other carbonate rock. Examples include the Michigan Basin pinnacle reefs and the Pennsylvanian/Permian reservoir in Kelly Snyder field of the Horseshoe Atoll. Pinnacle reefs, atolls, and bioherms are subcategories.

6 Slope - Developed in carbonate submarine-fan and debris-flow deposits associated with basin slopes. The Bone Springs formation in the Deleware Basin is an example of this fairly rare category. Turbidity flows, debris flows and carbonate mounds are subcategories.

7 Basin - Chalk deposits from pelagic organisms (coccoliths, coccospheres) on drowned platforms and basin floors. Examples are the Niobrara formation of western Kansas and the Austin Chalk of the Texas Gulf Coast. Basin floors and drowned platforms are subcategories.

CARBONATE DIAGENETIC OVERPRINT

1 Compaction/cementation - These processes reduce the quality (porosity, permeability) of the reservoir. Some degree of selective grain dissolution is included in this category. Examples are the Fairway (Cretaceous) reservoir in the East Texas Basin and the Mondak (Mississippian) reservoir in the Williston Basin.

2 Grain Enhancement - Reservoirs in which early subaerial (land as opposed to underwater) diagenetic processes improve reservoir quality by altering mud-dominated tidal-flat sediment to fenestral (window-like openings in the pore structure) and interpisolithic (pea shaped grains) pore types. An example is the Mississippian reservoir in Glenburn field in the Williston Basin.

3 Dolomitization With Evaporites - Reservoirs that produce from dolomites that contain considerable anhydrite or gypsum and whose principal pore types are intercrystalline, intergranular, and separate-vug. Examples are the Grayburg reservoir in Dune field at the edge of the Central Basin Platform and the San Andres reservoir in Wasson field in the Permian Basin.

4 Dolomitization - Dolomitic reservoirs that do not contain large amounts of sulfates (anhydrite, gypsum). Pores types are intercrystalline, intergranular, and separate-vug. The San Andres reservoir in Yates field is an example.

5 Massive Dissolution - Carbonate reservoirs with karsting (underground streams, sinks, and caverns) that results in collapse breccias, connected vugs, cave fills, and fracturing. The primary pore types are fractures, interbreccia-block, large connected vugs, and caverns. Other pore types may also be present. The Ellenburger reservoir in Emma field in West Texas is an example.

6 Silicification - Carbonate reservoirs where the dominant process is conversion to or impregnation with silica. Pore space is located between small quartz crystals or globules and in separate vugs. The Devonian reservoir in Block 31 field in the Permian Basin. is an example.

CARBONATE STRUCTURAL STYLE

1 Unstructured - Carbonate reservoirs that are not structured on an intrareservoir scale. An examples is the Grayburg reservoir in Dune field in the Permian Basin.

2 Fractured - Carbonate reservoirs where natural-fracture porosity is the principal permeability control in the reservoir. An example is the Mississippian reservoir in Mondak field, Williston Basin.

3 Faulted - Carbonate reservoirs where faults effectively compartmentalize the reservoir on an intrareservoir scale and where natural fracture porosity is not significant. Subcategories are normal, reverse, and strike-slip faults.

4 Folded - Carbonate reservoirs which are effectively compartmentalized by complex folding.

5 Fault/folded - Carbonate reservoirs where folding and faulting are of major importance in compartmentalization.

SILICICLASTIC DEPOSITIONAL SYSTEM

1 Eolian - Sandy reservoirs arranged by the wind, not restricted to deserts. Geometry and internal characteristics vary as a function of their depositional environment. Subcategories include ergs (a vast region covered deeply with pure sand and occupied by dunes) and coastal dunes. The Weber reservoir in Rangely field, western Colorado, is an example of the erg type.

2 Lacustrine - Deposited in a lake environment, may be beaches, deltas, fans, etc. Examples are the Eocene reservoirs of Duchesne and Altamont fields in the Uinta Basin, western Wyoming. Basin margin and basin center are subcategories.

3 Alluvial-fan - Formed where a faster flowing tributary enters a larger stream or braided-stream deposits which are formed where a stream is divided and reunited with itself many times. Most reservoirs are braided-stream deposits usually along the front of higher mountain blocks. Fan deltas which are formed by streams flowing into standing water are included in this category. Examples are the Triassic reservoirs in Prudoe Bay field, North Slope of Alaska, and the Jurassic reservoirs in Kern River field, San Joaquin valley of California. Subcategories are stream-dominated fans, fan deltas, and arid/semi-arid fans.

4 Fluvial - Sand-body deposits formed in rivers ranging in type from braided-stream sheets to coalesing point-bars of meandering streams. Examples are the Cretaceous reservoirs in the Cutbank field of northern Montana and the Morrow channel reservoirs in fields in southeast Colorado and southwest Kansas. Subcategories are meandering and braided.

5 Deltaic - Mainly distributary channel and steam-mouth bar type sand bodies and associated delta fringe strike sands. Subcategories are fluvial-dominated, wave-dominated, and tide-dominated reservoirs. Examples are the Eocene reservoirs in Mercy and Livingston fields, southeast Texas and the Cretaceous reservoirs in the giant East Texas Woodbine field.

6 Strandplain - Sand deposits occurring in long narrow belts paralleling old shorelines. Subcategories are barrier core, barrier shoreface, back barrier, tidal channel, and washover fan/tidal delta. Examples are the Cretaceous reservoirs in Bisti field, San Jaun Basin, New Mexico, and the Oligocene reservoir in TCB-East in south Texas.

7 Shelf - Sand deposits formed in the area from near shore but permanently under water to the point where there is a steep decent in the slope of the bottom (usually about 65 fathoms of depth). Examples are the Cretaceous reservoirs in the House Creek and Hartzog fields, Powder River Basin Wyoming.

8 Slope/basin - Sand deposits formed in the area between the shelf and deep basin. Subcategories are turbidite fans and debris fans. The Tertiary reservoirs in the southern California fields, in particular the Miocene reservoirs in the Elk Hills field, San Joaquin Basin, and the Pliocene reservoirs in the Ventura field, Santa Barbara Basin.

9 Deep Basin - Sand deposits formed in deep ocean basins and tectonic trenches. An example is the Miocene reservoirs in the Monterey field, southern California.

SILICICLASTIC DIAGENETIC OVERPRINT

1 Compaction/cementation - These processes reduce the quality (porosity, permeability) of the reservoir. Some degree of selective grain dissolution is included in this category. Examples are the Travis Peak reservoir in the Appleby North field, East Texas Basin which has lost porosity mainly by extensive quartz cementation and the Nugget sandstone reservoir in the Anschultz Ranch East field, Utah, which has lost porosity mainly by mechanical compaction and intergranular pressure solution.

2 Grain dissolution - This process improves reservoir quality (porosity, permeability). An example is the Frio Formation in Chocolate Bayou field in coastal Texas.

3 Authigenic clay - Reservoirs that contain significant volumes of authigenic (formed after deposition of sediment). Most common types are illite, smectite, mixed-layer illite-smectite, chlorite, and kaolinite. Examples are the Aux Vases Formation in the Illinois Basin and the lower Tuscaloosa Little Creek reservoir in Mississippi.

4 Chertification - This silica is derived by alteration of siliceous organisms which form a cement that later recrystallizes to chert. This is not a common process. Examples are the Miocene reservoir in the Monterey field, California, and the laterally equivalent turbidite sandstones in Beta and Wilmington fields, Los Angeles Basin.

SILICICLASTIC STRUCTURAL STYLE

1 Unstructured - Sandstone reservoirs that are not structured on an intrareservoir scale. An example is the Woodbine reservoir of the East Texas field.

2 Fractured - Sandstone reservoirs where natural-fracture porosity is the principal permeability control in the reservoir. An example is the Permian reservoir in the Spraberry field, Permian Basin.

3 Faulted - Sandstone reservoirs where faults effectively compartmentalize the reservoir on an intrareservoir scale and where natural fracture porosity is not significant. The Clam Lake field, a piercement salt-dome field is an example. Subcategories are normal, reverse, and strike-slip faults.

4 Folded - Sandstone reservoirs which are effectively compartmentalized by complex folding.

5 Fault/folded - Sandstone reservoirs where folding and faulting are of major importance in compartmentalization.